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Economic Load Dispatch Problem with Valve – Point Effect Using a Binary Bat Algorithm

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Abstract—**This paper proposes application of BAT algorithm for solving economic load dispatch problem. BAT algorithmic rule is predicated on the localization characteristics of micro bats. The proposed approach has been examined and tested with the numerical results of economic load dispatch problems with three and five generating units with valve - point loading without considering prohibited operating zones and ramp rate limits. The results of the projected BAT formula are compared with that of other techniques such as lambda iteration, GA, PSO, APSO, EP, ABC and basic principle. For each case, the projected algorithmic program outperforms the answer reported for the existing algorithms. Additionally, the promising results show the hardness, quick convergence and potency of the projected technique.**

Index Terms—**Binary BAT algorithm, Economic load dispatch, valve-point effect, mathematical modeling.**

I. Introduction

The economic load dispatch is an important real time drawback, in properly allocating the important power demand among the online generating units. Traditional optimization techniques [1] such as the lambda iteration method, gradient method, the linear programming method and Newton's method are used to solve the ELD problem with monotonically increasing cost function. But they are highly sensitive to starting points and often converge to local optimum or diverge altogether. In reality, the input-output characteristic of generating units are nonlinear due to valve-point loading and more advanced algorithms are worth developing to obtain accurate dispatch results.

Many works are in literature to solve the ELD problem with valve-point loading. Dynamic programming (DP) is one of the approaches to solve the non-convex ELD problem. However, the DP method requires too many computational resources in order to provide accurate results for large scale power systems [1], [2]. Over the past few years, in order to solve this problem, many stochastic methods have been developed such as GA [3], Evolutionary Programming (EP) [4], [5], Simulated Annealing (SA) [6], and Particle Swarm Optimization (PSO) [7]. They may prove to be very effective in solving non-linear ED problems without any restriction on the shape of the cost curves. SA is applied in many power system problems. Nevertheless, the setting of control parameters of the SA algorithm is a difficult task and convergence speed is slow when applied to a real system [8]. Tabu Search (TS), a heuristic search approach has also been applied to solve the ED problem [9]. Though GA methods have been employed successfully to solve complex optimization problems, traditional GA has some drawbacks when applied to multidimensional, high-precision numerical problems. The basic disadvantage of GA is the fact that they may miss the optimum and provide a near-optimum solution in a limited runtime period [10]. Moreover, the premature convergence of GA degrades its performance and reduces its search capability that leads to a higher probability towards obtaining a local optimum [11]. EP seems to be a good method to solve optimization issues. Once applied to issues consisting of additional number of local optima the solutions obtained from EP method is just near global optimum. In addition, GA and EP take long simulation time in order to obtain answer for such issues. Therefore, hybrid strategies combining two or more improvement strategies were introduced [12]-[15]. These techniques are more efficient than the conventional procedures because of their heuristic search procedure. Recent research endeavours, therefore, have been directed towards the application of these techniques.

In this paper, bat algorithm (BA) was based on the echolocation is proposed to solve the ELD problem with non-convex functions to consider non-linear generator characteristics such as valve-point effect. The echolocation based algorithm described in this paper is a search algorithm capable of locating optimal solutions efficiently. The effectiveness of the proposed algorithm is demonstrated using three and five generating unit test systems. Results show that the algorithm can handle complex multi-model optimization problems.

II. Economic Load Dispatch Problem

The economic load dispatch problem is defined as to minimize the total operating cost of a power system while meeting the total load plus transmission losses with in the generator limits. Mathematically, the problem is outlined on minimize equation (1) subjected to the energy balance equation given by (2) and the inequality constraints given by equation (3).

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$$F_i(P_i) = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i) \quad (1)$$

$$\sum_{i=1}^{NG} P_i = P_D + P_L \quad (2)$$

$$P_{imin} \le P_i \le P_{imax} (\mathrm{i} = 1, 2 \ldots \mathrm{NG}) \quad (3)$$

where

a_i, b_i, and c_i are the cost coefficients
P_D is the load demand
P_{gi} is the real power generation
P_L is the transmission power loss
NG is the number of generation buses.

One of the important, simple but approximate methods of expressing transmission loss as a function of generator power is through B- coefficients. The general form of the loss formula using B- coefficients is

$$P_i = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_i B_{ij} P_j \quad \mathrm{MW} \quad (4)$$

where

P_i and P_j are the real power generations at the i^{th}, j^{th} buses respectively
B_{ij} are loss coefficients.

The above transmission loss formula of Eq. (4) is known as the George's formula.

In normal economic load dispatch problem the input - output characteristics of a generator are approximated using quadratic functions, underneath the idea that the progressive cost curves of the units are monotonically increasing piecewise-linear functions. However, real input- output characteristics display higher order nonlinearities and discontinuities due to valve – point loading in fossil fuel burning plants.

The generating units with multi – valve steam turbines exhibit a greater variation in the fuel cost functions. The valve – point effects introduces ripples in the heat rate curves. Mathematically operating cost is defined as:

$$F_i(P_i) = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i + |d_i * \sin\{e_i * (P_i^{min} - P_i)\}|) \quad (5)$$

where

a_i, b_i, c_i, d_i and e_i are the cost coefficients of the i^{th} unit.

Mathematically, economic dispatch problem considering valve point loading is defined as equation (5) subjected to: energy balance equation is given by Eq. (2) and inequality constraints are given by Eq. (3) respectively.

III. Proposed Methodology

In this section, the solution procedure for the proposed BAT algorithm is described.

A. BAT Algorithm

The Bat algorithm was developed by Xin-She Yang in 2010 [16]. The algorithm exploits the so-called echolocation of the bats. The bats use sonar echoes to detect and avoid obstacles. It is generally known that sound pulses are transformed into a frequency which reflects from obstacles. The bats navigate by using the time delay from emission to reflection. They typically emit short, loud sound impulses. The pulse rate is usually defined as 10 to 20 times per second. After hitting and reflecting, the bats transform their own pulse into useful information to gauge how far away the prey is. The bats are using wavelengths that vary in the range from 0.7 to 17 mm or inbound frequencies of 20-500 kHz. To implement the algorithm, the pulse frequency and the rate have to be defined. The pulse rate can be simply determined in the range from 0 to 1, where 0 means that there is no emission and 1 means that the bats' emitting is their maximum [17, 18, 19]. The bat behaviour can be used to formulate a new BA. Yang [18] used three generalized rules when implementing the bat algorithms:

1. All the bats use an echolocation to sense the distance and they also guess the difference between the food/prey and background barriers in a somewhat magical way.
2. When searching for their prey, the bats y randomly with velocity v_i at position x_i with fixed frequency f_{min}, varying wavelength λ and loudness A_0. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission r ε [0, 1], depending on the proximity of their target.
3. Although the loudness can vary in many ways, we assume that it varies from a large (positive) A_0 to a minimum constant value A_{min}.

For simplicity, we do not use ray tracing in this algorithm, though it can form an interesting feature for further extension. In general, ray tracing can be computational extensive, but it can be a very useful feature for computational geometry and other applications. Furthermore, a given frequency is intrinsically linked to a wavelength. For example, a frequency range of [20 kHz, 500 kHz] corresponds to a range of wavelengths from 0.7mm to 17mm in the air. Therefore, we can describe the change either in terms of frequency f or wavelength λ to suit different applications, depending on the ease of implementation and other factors.

B. BAT Motion

Each bat is associated with a velocity v_i^t and a location x_i^t, at iteration t, in a d - dimensional search or solution space

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (6)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*) f_i \quad (7)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (8)$$

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where β ε [0, 1] is a random vector drawn from a uniform distribution. As mentioned earlier, we can either use wavelengths or frequencies for implementation, we will use $f_{min} = 0$ and $f_{max} = O(1)$, depending on the domain size of the problem of interest. Initially, each bat is randomly assigned a frequency which is drawn uniformly from [fmin, fmax]. For this reason, bat algorithm can be considered as a frequency-tuning algorithm to provide a balanced combination of exploration and exploitation. The loudness and pulse emission rates essentially provide a mechanism for automatic control and auto zooming into the region with promising solutions.

C. Variations of Loudness and Pulse Rates

In order to provide an effective mechanism to control the exploration and exploitation and switch to exploitation stage when necessary, we have to vary the loudness A_i and the rate r_i of pulse emission during the iterations. Since the loudness usually decreases once a bat has found its prey, while the rate of pulse emission increases, the loudness can be chosen as any value of convenience, between A_{min} and A_{max}, assuming $A_{min} = 0$ means that a bat has just found the prey and temporarily stop emitting any sound. With these assumptions, we have

$$A_i^{t+1} = \propto A_i^t, \qquad r_i^{t+1} = r_i^t[1 - \exp(-\gamma t)], \tag{9}$$

where α and γ are constants.

In essence, here α is similar to the cooling factor of a cooling schedule in simulated annealing. For any $0 < \alpha < 1$ and $\gamma > 0$, we have

$$A_i^t \to 0, r_i^t \to r_i^0, \text{ as } t \to \infty \tag{10}$$

In the simplest case, we can use α = γ, and we have used α = γ = 0.9 to 0.98 in our simulations.

D. Variants of BAT Algorithm

The Binary bat algorithm has many advantages, and one of the key advantages is that it can provide very quick convergence at a very initial stage by switching from exploration to exploitation. This makes it an efficient algorithm for applications such as classifications and others when a quick solution is needed. However, if we allow the algorithm to switch to exploitation stage too quickly by varying *A* and *r* too quickly, it may lead to stagnation after some initial stage.

E. Pseudo Code of BAT Algorithm

```
Objective function f(x), x = (x_1,....,x_d)^T
Initialize the bat population x_i and v_i for i = 1.....n
Define pulse frequency Q_i ε [Q_min, Q_max]
Initialize pulse rates r_i and the loudness A_i
while (t < T_max) // number of iterations
 Generate new solutions by adjusting frequency and
   update velocities and locations/solutions [Eq.(7) to (9)]
   if (rand (0; 1) > r_i)
      Select a solution among the best solutions
      Generate a local solution around the best solution
   end if
   Generate a new solution by flying randomly
   if (rand (0; 1) < A_i and f(x_i) < f(x))
      Accept the new solutions
      Increase r_i and reduce A_i
   end if
   Rank the bats and find the current best
end
Post process results and visualization
```

IV. Similation Results And Discussion

The applicability and validity of the BAT algorithm for practical applications has been tested on various test cases. The obtained best solution in fifty runs are compared with the results obtained using GA. All the programs are developed using MATLAB 7.8.0 (2009a) and the system configuration is core i3 processor with 2.30 GHz speed and 6 GB RAM.

A. Settings of BAT Algorithm Parameters

The Parameters for BAT algorithm considered here are: n=20; A=0.9; r=0.1; f_min= 0; f_max= 2. The proposed BAT algorithm stopping criteria is based on maximum-generation=100.

B. Numerical Solutions

i. Test Case 1: The system consists of three thermal units. The cost coefficients of all thermal generating units with valve point effect are listed in Table 1. The transmission losses are neglected. Prohibited zones and ramp rate limits of generating units are not considered. The economic load dispatch problem is solved to meet a load demand of 850 MW and 1050 MW. This test system comprises of three generating units and six buses and the unit data are adapted from [3]. In this case, valve-point effect is included and transmission losses are neglected. The total load demand for the system is 850 MW and 1050MW. Results obtained for the proposed method is shown in Table 2 and the results are compared with Lambda, GA, PSO and ABC. It was reported in that the global optimum solution found for the 3-generator system is 8121.8568 Rs/hr and 10123.6953 Rs/hr.

From the results in Table 2 it is explicit that BAT algorithm has succeeded in finding the global optimum solution that has been reported in the literature. Fig. 1: shows the convergence tendency of proposed BAT algorithm based strategy for power demand of 850 MW and 1050 MW. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property.

ii. Test Case II: The system consists of five thermal units [1]. The cost coefficients of all thermal generating units with valve point effect are listed in table (3). The economic load dispatch problem is solved to meet a load demand of 730 MW. This test system comprises of five generating units. In this case, valve-point effect is included and transmission losses are neglected. Prohibited zones and ramp rate limits of generating units are not considered. The total load demand for the system is 750 MW.

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TABLE: 1 COST COEFFICIENTS FOR THREE GENERATING UNITS

Unit	Fuel cost coefficients					(MW)	(MW)
	a_i	b_i	c_i	d_i	e_i		
G1	0.0016	7.92	561.0	300	0.032	100	600
G2	0.0048	7.92	78.0	150	0.063	50	200
G3	0.0019	7.85	310.0	200	0.042	100	400

TABLE: II COMPARISON OF RESULTS FOR TEST CASE 1

Load demand	Parameter	Lambda	GA	PSO	ABC	BAT
850 MW	P1,MW	382.258	382.2552	394.5243	300.266	296.3495
	P2,MW	127.419	127.4184	200.000	149.733	199.6002
	P3,MW	340.323	340.3202	255.4756	400.000	334.0503
	Total cost, Rs/h	8575.68	8575.64	8280.81	8253.10	8121.8568
1050 MW	P1, MW	487.500	487.498	492.699	492.6991	492.6991
	P2, MW	162.500	162.499	157.30	157.301	158.0995
	P3, MW	400.000	400.000	400.00	400.00	399.2014
	Total cost, Rs/h	10212.459	10212.44	10123.73	10123.73	10123.6953

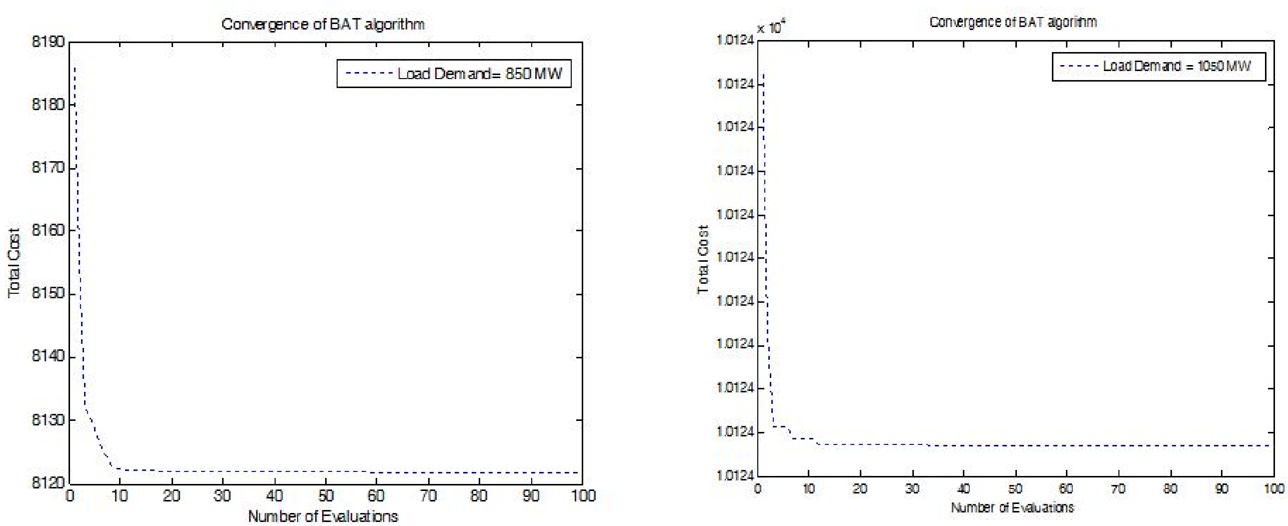

Fig. 1 Convergence characteristics of three generating units.

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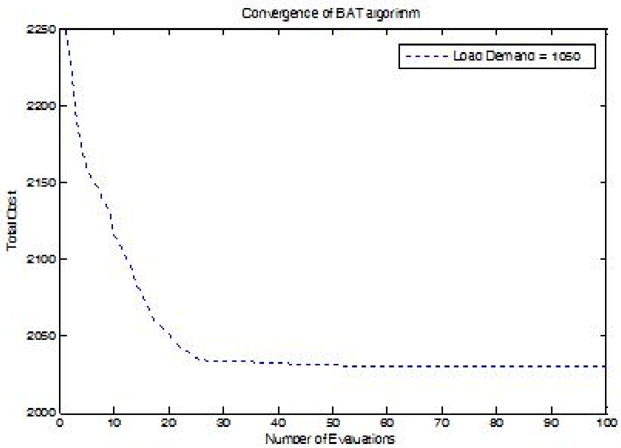

Fig.2 Convergence characteristics of five generating units.

Results obtained for the proposed method is shown in Table 4 and the results are compared with Lambda, GA, PSO and ABC. It was reported in that the global optimum solution found for the 5-generator system is 2029.668 Rs/hr. From the results in Table 4 it is explicit thatBAT algorithm has succeeded in finding the global optimum solution that has been reported in the literature.

Fig. 2 shows the convergence tendency of proposed BAT algorithm based strategy for power demand of 750 MW is plotted in Fig. 3. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property.

V. Conclusion

In this paper, a new BAT algorithm has been proposed. In order to prove the effectiveness of algorithm it is applied to economic load dispatch problem with three and five generating units. The results obtained by proposed method were compared to those obtained by lambda iteration method, GA, PSO, APSO and ABC. The comparison shows that BAT algorithm performs better than above mentioned methods. The BAT algorithm has superior features, including quality of solution, stable convergence characteristics and good computational efficiency. Therefore, this results shows that BAT optimization is a promising technique for solving complicated problems in power system.

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Table III. Cost coefficients for Three Generating units

Unit	Fuel cost coefficients					(MW)	(MW)
	a_i	b_i	c_i	d_i	e_i		
G1	0.0015	1.8	40.0	200.0	0.035	50	300
G2	0.0030	1.8	60.0	140.0	0.040	20	125
G3	0.0012	2.1	100.0	160.0	0.038	30	175
G4	0.0080	2.0	25.0	100.0	0.042	10	75
G5	0.0010	2.0	120.0	180.0	0.037	40	250

Table: IV Comparison of results for test case 2.

Load demand	Parameter	Lambda	GA	PSO	APSO[1]	EP[1]	ABC	BAT
730 MW	P1, MW	218.028	218.0184	229.5195	225.3845	229.8030	229.5247	229.5209
	P2, MW	109.014	109.0092	125.00	113.020	101.5736	102.0669	102.9878
	P3, MW	147.535	147.5229	175.00	109.4146	113.7999	113.4005	112.6753
	P4,MW	28.380	28.37844	75.00	73.11176	75.000	75.000	75.000
	P5,MW	272.042	227.0275	125.4804	209.0692	209.8235	210.0079	209.816
	Total cost, Rs/h	2412.709	2412.538	2252.572	2140.97	2030.673	2030.259	2029.668

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